

Accelerator Physics of the VLHC

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3.9 Parameter tables

Storage energy	87.5	TeV
Peak luminosity	2×10^{34}	$\text{cm}^{-2}\text{s}^{-1}$
Number of interaction points	2	
Arc average radius	35.0	km
Distance from IP to first magnet	30	m
Injection energy	10	TeV
Fill time	30	s
Acceleration time	2000	s
Transverse emittance, rms (inject)	1.5	μm
Longitudinal emittance, rms (inject)	2.0	eV-s

Table 13: Primary design parameters.

Bend field at storage	9.765	T
Circumference	233.037	km
Revolution frequency	1.286	Hz
Horizontal tune	218.19	
Vertical tune	212.18	
Transition gamma	194.13	
Slip factor	2.653×10^{-5}	
Phase advance per cell	90.0	deg
Maximum arc beta	459	m
Maximum arc dispersion	1.42	m
Max RMS arc betatron size (inject)	.254	mm
Rigidity at injection	3.336×10^4	Tm
Rigidity at store	2.919×10^5	Tm
SYNCHROTRON RADIATION AT STORE		
Energy loss per turn	15.3	MeV
Radiation damping time (τ_0)	2.48	hr
Natural transverse emittance (H)	.0397	μm
Natural RMS momentum width	5.5×10^{-6}	

Table 14: Lattice parameters, including natural synchrotron values.

Total cross section at store	1.5×10^{-25}	cm^2
Peak collision debris power	84	kW
Fraction of buckets filled	90	%
Number of buckets	41280	
Number of bunches	37152	
Bunch spacing (53.1 MHz)	5.645	m
	18.8	ns
STORE BEGINNING		
Protons per bunch	9.0	10^9
Protons per beam	3.34	10^{14}
Beam current	68.9	mA
Dipole linear heat load	5.6	W/m
Total synch. rad. power (2 beams)	2.1	MW
Total stored energy (2 beams)	9.37	GJ
Emittance, rms (H and V)	1.5	μm
Momentum width, rms	54.5	10^{-6}
Arc bunch size	85.9	μm
Full crossing angle	65.9	μrad
EARLY PLATEAU (Flat beams)		
Beam-beam parameter	.008	
Emittance, rms (H)	.210	μm
Emittance, rms (V)	.021	μm
Momentum width, rms	40.0	10^{-6}
Arc bunch size (H)	32.2	μm
IP bunch size (H)	2.89	μm
IP bunch size (V)	.29	μm
Full crossing angle	6.3	μrad
Collision beta (H)	3.7	m
Collision beta (V)	.37	m
EARLY PLATEAU (Round beams)		
Beam-beam parameter	0.008	
Emittance, rms		μm
Momentum width, rms		10^{-6}
Arc bunch size		μm
IP bunch size		μm
Full crossing angle		μrad
Collision beta		m

Table 15: Store parameters

Harmonic number	371520	
RF frequency (9×53.1)	478.0	MHz
INJECTION		
Longitudinal rms emittance	2.0	eV-s
RF voltage	50.0	MV
Longitudinal beta	351	m
Momentum width, rms	233.1	10^{-6}
Bunch length, rms	81.9	mm
Synchrotron tune	.00280	
Synchrotron frequency	3.60	Hz
STORE BEGINNING		
Longitudinal rms emittance	2.0	eV-s
RF voltage	100.0	MV
Longitudinal beta	735	m
Momentum width, rms	54.5	10^{-6}
Bunch length, rms	40.0	m
Synchrotron tune	.00134	
Synchrotron frequency	1.72	Hz
STORE PLATEAU		
Longitudinal rms emittance	1.08	eV-s
RF voltage	100.0	MV
Longitudinal beta	735	m
Momentum width, rms	40.0	10^{-6}
Bunch length, rms	29.4	m
Synchrotron tune	.00134	
Synchrotron frequency	1.72	Hz

Table 16: RF and longitudinal parameters.

Module	Arc	DS	IA	DM8	IR	DM	X	DM	IR	DM8	IA	DS
L/L_{hc}	780	3	10	8	12	6	2	6	12	8	10	3

Table 17: Sequence of optical modules around half of the VLHC (mnemonic version).

Module	Alias	L/L_{hc}	Comment
Dispersion Suppressor	DS	3	
Injection/Abort straight	IA	10	
Dispersion Module	DM8	8	contains 2 arc half cells
Interaction Region	IR	12	
Dispersion Module	DM	6	
Crossing "straight"	X	2	
Dispersion Module	DM	6	
Interaction Region	IR	12	
Dispersion Module	DM8	8	contains 2 arc half cells
Injection/Abort straight	IA	10	
Dispersion Suppressor	DS	3	
Utility total		80	
Arc		780	
GRAND TOTAL		1720	2 arcs plus 2 utilities

Table 18: Sequence of optical modules in the on-site utility region of the VLHC.

DIPOLE		
Field at injection	1.116	T
Field at store	9.765	T
Bend radius	29.887	km
Coil full width	40	mm
Liner full width	20	mm
Vertical bore separation	.29	m
Stored energy (2 bores)	828	kJ/m
QUADRUPOLE		
Gradient at injection	45.7	T/m
Gradient at store	400	T/m
Stored energy (2 bores)	418	kJ/m
CORRECTORS		
Corrector magnetic length	1.0	m
Dipole corrector max strength		Tm
Skew quad max strength		T
Sextupole max strength		T/m
ARC CELLS		
Half cell harmonic	24	
Half cell length	135.486	m
Half cell bend angle	3.875	mrad
Half cell count	1568	
Dipoles per half cell	7	
Dipole count, total	10976	
Dipole magnetic length	16.546	m
Dipole fill factor	85.5	%
Quad magnetic length	8.066	m
DISPERSION SUPPRESSOR CELLS		
Half cell harmonic	18	
Half cell length	101.614	m
Half cell bend angle	2.583	mrad
Half cell count	80	
Dipoles per half cell	5	
Dipole count, total	400	
Dipole magnetic length	15.443	m
Dipole fill factor	76.0	%
Quad magnetic length	10.775	m

Table 19: Arc and dispersion suppressor magnet and cell parameters.

Separation distance		m
Dipole coil ID		mm
IR quad pole tip field	12.0	T
IR quad gradient		T/m

Table 20: Interaction region magnet parameters.

Magnet	Misalignment tolerances	Roll tolerances	Main field error tolerances
Arc dipole			
Arc quadrupole			
IR dipole			
IR quadrupole			

Table 21: Alignment tolerances

3.10 Magnet reference harmonics

The expansion for the field error in a dipole magnet is written in terms of coefficients (b_n, a_n) as

$$\Delta(B_y + iB_x) = B_0 10^{-4} \sum_{n=1} (b_n + ia_n) \left(\frac{x + iy}{r_0} \right)^n \quad (32)$$

where B_0 is the main dipole field and $r_0 = 10$ mm is the reference radius in all cases. Similarly, for a quadrupole

$$\Delta(B_y + iB_x) = G_0 r_0 10^{-4} \sum_{n=2} (b_n + ia_n) \left(\frac{x + iy}{r_0} \right)^n \quad (33)$$

where G_0 is the main quadrupole field gradient. In the following tables, for each set of magnets, b_n (a_n) is the mean or systematic value of the normal (skew) harmonic, $\Delta(b_n)$ is the uncertainty of the systematic normal harmonic, and $\sigma(b_n)$ is the standard deviation of the normal harmonic. The convention in which $n = 2$ is sextupole is used throughout.

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
1		.5	1.2	.005	.5	1.2
2	-2.0	1.0	.85		.3	.85
3		.2	.3	-.001	.2	.3
4	-.5	.2	.12		.2	.12
5			.05	-.002		.05
6	-.001		.02			.02
7			.008	.011		.008
8	-.046		.005			.005
9			.001	.003		.001

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
1		.5	1.2		.5	1.2
2		.5	.6		.3	.6
3		.2	.3	-.001	.2	.3
4	-.001	.05	.1		.05	.1
5			.05	-.002		.05
6	-.001		.02			.02
7			.008	.011		.008
8	-.046		.005			.005
9			.001	.003		.001

Table 22: Arc dipole body harmonics, v1.0. At injection with $B = 2$ T (top), and at storage with $B = 10$ T (bottom).

The injection energy dropped from the 20 TeV value used for v1.0 harmonics to 10 TeV. The injection field reduces from 2.28 T to 1.14 T and injection field gradient from 90 T/m to 45 T/m. The components of field harmonics related to the coil magnetization effect at injection have been checked and corrected if necessary.

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
2		.75	1.875		.75	1.875
3	.004	.5	.875		.5	.875
4		.125	.375		.125	.375
5	-2.5	.25	.25		.125	.25
6			.075			.075
7	-.0035		.025			.025
8			.025			.025
9	.1	.025	.0125			.0125

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
2		.75	1.875	.175	.75	1.875
3	.03	.50	.875		.5	.875
4		.125	.375		.125	.375
5	.03	.075	.2		.075	.2
6			.075			.075
7	-.0035		.025			.025
8			.025			.025
9	-.004	.025	.0125			.0125

Table 23: Arc quadrupole body harmonics, v1.0. At injection with $G = 80$ T/m (top), and at storage with $G = 400$ T/m (bottom).

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
1		.5	1.2		.5	1.2
2	-2.0	1.0	.85		.3	.85
3		.05	.35		.05	.35
4	.5	.2	.12		.2	.12
5	-.006	.006	.05		.002	.05
6	-.004	.007	.02			.02
7	.015	.015	.008	.01	.005	.008
8	-.065	.065	.005			.005
9	-.006	.006	.001	.002	.001	.001

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
1		.5	1.2		.5	1.2
2		.5	.6		.3	.6
3		.05	.3		.05	.3
4		.05	.1		.05	.1
5	-.006	.006	.05		.002	.05
6	-.004	.007	.02			.02
7	.015	.015	.008	.01	.005	.008
8	-.065	.065	.005			.005
9	-.006	.006	.001	.002	.001	.001

Table 24: Arc dipole body harmonics, v1.1. At injection with $B = 1.14$ T (top), and at storage with $B = 10$ T (bottom).

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
2		.25	1.875		.25	1.875
3		.25	.875		.25	.875
4		.125	.375		.125	.375
5	-1.25	.25	.25		.125	.25
6			.075			.075
7	-.004		.025			.025
8			.025			.025
9	.075	.025	.013		.013	.0125

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
2		.5	1.875	.175	.5	1.875
3		.25	.875		.25	.875
4		.125	.375		.125	.375
5	.025	.025	.2		.025	.2
6			.075			.075
7	-.0035		.025			.025
8			.025			.025
9	-.004	.003	.0125			.0125

Table 25: Arc quadrupole body harmonics, v1.1. At injection with $G = 45$ T/m (top), and at storage with $G = 400$ T/m (bottom).

n	b_n	Δb_n	$\sigma(b_n)$	a_n	Δa_n	$\sigma(a_n)$
2		2	2	3	3	1
3	2	2	1		1	1
4		1	1	1.5	1.5	1
5	1	1	.5		1	.2
6		.1	.1	.5	.5	.5
7	.5	.5	.1		.2	.1
8		.1	.1	.3	.3	.1
9	.5	.5	.1		.1	.1

Table 26: Interaction region quadrupole integrated harmonics for Q1 and Q2, v1.0.